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Comparison of Hydroacoustic and Net Estimates of Fish Guidance Efficiency of an Extended Submersible Bar Screen at John Day Dam

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Abstract.--We compared results of the hydroacoustic and netting methods of estimating guided and unguided fish passage and the fish-guidance efficiency (FGE) of an extended submersible bar screen at John Day Dam, Columbia River, USA. Hydroacoustic counts of guided fish were significantly correlated with concurrent gatewell catches (r^2 = 0.73; N = 39) as were hydroacoustic counts of unguided fish with fyke-net catches (r^2 = 0.71; N = 39). However, hydroacoustic sampling significantly underestimated both guided and unguided fish passage relative to netting estimates. We could not explain the underestimates by modeling hydroacoustic detectability, and the distribution of fish passage across the intake width was not skewed away from transducer sampling volumes. Hydroacoustics provided relatively unbiased estimates of fish guidance efficiency [guided / (guided + unguided)] because of compensating errors in the numerator and denominator. The best correlation between net and hydroacoustic estimates of efficiency (r^2 = 0.85; N = 40) had a slope of 0.91 when the intercept was set to zero. Precision of hydroacoustic estimates increased 50% and the r^2 of the correlation line increased 19% when hydroacoustic-sampling duration was extended from the typical netting duration of 1-2 h to 4 h. Further increases in hydroacoustic sampling duration from 5-9 h provided no significant improvement in correlations. Strong correlations between estimates of FGE derived from netting and hydroacoustic sampling are reassuring and useful because both methods have advantages that can be exploited to improve overall sampling effectiveness at a hydropower project. The derivation of a universally applicable relation

between hydroacoustic and physical capture estimates of fish passage is not possible given many potential deployment-depended biases in estimates.

Introduction

Researchers in the Columbia and Snake River basin first began estimating the fish guidance efficiency (FGE) of submerged traveling screens in the 1970s (Gessel et al. 1991) and of extended submersible bar screens (ESBS) after 1991 (Bardy et al. 1991). A fish guidance screen is located in each of the three intake bays that make up a single turbine unit. The screens are designed to divert juvenile salmon in the upper portion of a turbine intake into a gatewell slot where they can pass through openings in the gatewell leading to a bypass channel around the dam. The screens function by modifying hydraulic characteristics of the flow they intercept and have an appreciable effect on the flow pattern through the turbine intake (Nestler and Davidson 1995). The underlying premise is that bypassed fish have a higher probability for survival during dam passage than fish passing through turbines. The FGE of guidance screens traditionally has been determined by the physical capture and enumeration of fish. Large dip-nets (Swan et al. 1979) are used to capture juvenile salmon from the gatewell slot above an intake to estimate numbers of guided fish. Fyke netting is used to physically capture fish in the intake downstream of the fish guidance screen. Fish captured by fyke netting are used to estimate the number and species composition of “unguided” fish, i.e., those not diverted into the gatewell slot by the screen (Gessel et al. 1991). Estimates of FGE are made by dividing the count of guided fish by the sum of counts of guided and unguided fish.

Fixed-aspect hydroacoustics also has a history of use to estimate guided and unguided fish and the FGE of submerged traveling screens at Rocky Reach (Steig et al. 1988), Little Goose (Johnson et al. 1987), McNary (Johnson and Schadt 1986), and Bonneville dams (Thorne and Kuehl 1989; Magne et al. 1989; Stansell et al. 1990). Bar screen efficiencies have been evaluated at Rock Island (Raemhild et al. 1988), Rocky Reach (Steig and Ransom 1989; Steig 1993; Steig and Nealson 1994; Steig et al. 1995; and Ransom et al. 1996), Lower Granite (Thorne and Kuehl 1990; Johnson et al. 1998), Wanapum (Ransom et al. 1996), and John Day (BioSonics Incorporated 1997; Brege et al. 1997) dams. Hydroacoustic estimates of juvenile salmon passage and guidance have been correlated with estimates based on net catches (Thorne and Kuehl 1989; Magne et al. 1989; Ransom et al. 1996).

Juvenile salmon migrating downstream past John Day Dam include chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), steelhead trout (O. mykiss), and sockeye salmon (O. nerka) from the Snake and Columbia Rivers and their tributaries. Passage typically is dominated by yearling fish in spring and sub-yearling fish in summer. When these data were collected in 1996, Snake River chinook and sockeye were listed as an endangered species.

The primary objective of this study was to compare hydroacoustic and net estimates of guided and unguided fish passage and FGE for an ESBS in turbine Intake 7b at John Day Dam in spring and summer. Increased understanding of potential biases is the primary benefit of comparing estimates by different methods. Secondary objectives were to determine diel and seasonal patterns in hydroacoustic estimates of fish passage and FGE.

John Day Dam is located on the Columbia River, 346 km upstream of the Pacific Ocean. From south to north, the Dam consists of a 602-m long powerhouse with 16 turbine units, a 381-m long spillway, and a navigation lock on the north shore. Each turbine unit is capable of passing 623 $m^3 s^{-1}$ discharge, generating 150 megawatts of power, and has three intakes, each 9.1-m wide and 22.9-m tall.

Methods

Fish guidance efficiency of the extended submersible bar screen in Turbine Intake 7b of John Day Dam was estimated in spring and summer by hydroacoustic and net sampling of guided and unguided juvenile salmon. Fish passage was sampled about 23 h per day with fixed-aspect hydroacoustic equipment (BioSonics, Incorporated 1997). The National Marine Fisheries Service dip netted in gatewell slot 7b and fished fyke nets downstream of the ESBS in intake 7b for 1-3 h per day (Brege et al. 1997).

The two methods for netting guided and unguided fish were quite different. Fyke nets were deployed once per day to sample unguided fish passing under the ESBS. Twenty-four fyke nets were attached three across and eight deep to a large frame. After turbine shutdown, the net frame was lowered into the bulkhead slot downstream of the gatewell slot (Figure 1). When deployed, the fyke-nets covered the entire cross section of turbine intake. Next, fish were dip-netted from the gatewell slot using a large steel dip basket that conformed to the size and shape of the slot, until the catch per dip was low. Then the turbine was started, and the dip basket was again used at 10-15 min intervals to collect guided fish accumulating in the gatewell slot above the ESBS (Brege et al. 1997). The objective of gatewell dipping was to capture all fish that entered the gatewell while the fyke nets were sampling. The duration of sampling depended upon the number of fish collected from the gatewell slot and an estimate of what the fyke net may have collected during the same period based upon historical FGE data. Fyke-net sampling began at 2000 h and ended between 2100 and 2300 h, when biologists estimated that 200 fish had been collected by both netting methods (Brege et al. 1997). Netting provided estimates of the number of guided and unguided fish but no estimate of variance for the day because only one sample was taken daily. The FGE for each species and all fish was calculated as:

$$FGE = \sum GW / (\sum GW + \sum FN)$$

where GW = gatewell catch and FN = fyke-net catch.

We examined the lateral distribution of catches of yearling chinook in spring and sub-yearling chinook in summer among the three columns of fyke nets. The objective was to determine whether the assumption of a uniform distribution of fish passage across the width of the intake was reasonable for expanding hydroacoustic counts. Analysis of variance was used to determine whether fish passage differed significantly among the left, middle, and right sides of the intake.

Hydroacoustic sampling was done with a 420 kHz BioSonics ES 2000 Echosounder and four 6°, single-beam transducers mounted inside the intake on trash racks near the centerline and aimed to count guided and unguided fish (Figure 1). Deployment of several transducers with slightly different aiming angles provided redundancy in case a transducer was aimed incorrectly or failed. Targets counted as fish had to return four or more echoes with less than a 4-ping gap and amplitudes exceeding an on-axis threshold of -62 decibels (dB referenced to 1 μPa at 1 m). In addition, fish passing through an up-looking hydroacoustic beam had to be > 8 m from the transducer to be classified as guided. Fish passing through a down-looking beam had to be > 13 m from the transducer to be counted as unguided.

Hydroacoustic FGE estimates were based upon counts from Transducers 1 and 2 (Figure 1) because they had the best aiming angles for detecting fish. Transducer 1 sampled all the way to bottom of the intake, unlike Transducer 3 whose beam was aimed too far downstream and intercepted the screen. Fish passing through the beam of Transducer 2 were in the acoustic beam slightly longer than fish passing through Transducer 4. However, Transducer 2 failed on July 2, 1996 forcing the use of Transducer 4 to count guided fish for the remainder of the study. Therefore, FGE estimates were based upon fish detected by Transducers 1 and 2 before July 2nd and Transducers 1 and 4 thereafter. Transducers 1 and 2 were fast multiplexed for six 5-min periods per hour at 10 pings s^{-1} each. These samples were interspersed with six 5-min samples with Transducer 4, which also had a 10 ping s^{-1} pulse repetition rate. Transducers were systematically sampled for about 23 h per day. A new randomized sampling sequence was used each day.

Every fish count was weighted by the ratio of the intake width to the diameter of the transducer sampling volume at the range of detection of fish. In a report to the U. S. Army Engineer District, BioSonics Incorporated (1997) provided weighted hourly counts and variances for guided and unguided fish and FGE. The FGE was estimated as:

$$FGE = \sum \text{Guided fish} / (\sum \text{Guided fish} + \sum \text{Unguided fish})$$

The variance in FGE was estimated (after Skalski et al. 1996) as:

$$FGE_{VAR} = FGE^2(1\text{-}FGE)^2[VAR_G/G^2 + VAR_{UG}/UG^2]$$

where: FGE_{VAR} is variance in FGE; VAR_G is variance in numbers of guided fish; G is the number of guided fish; VAR_{UG} is the variance in numbers of unguided fish; and UG is the number of unguided fish. We estimated numbers of guided and unguided fish for periods > 1 h to 1 d by summing hourly counts and variances. Hydroacoustic estimates are for all juvenile salmonids combined, i.e., the run-at-large, because fish species cannot be identified hydroacoustically.

We investigated the reasonableness of factors for expanding guided and unguided hydroacoustic counts as a function of range from the transducer by modeling the hydroacoustic detectability of fish passing through sampling volumes of Transducers 1, 2, and 4. Variables and values used for modeling are presented in Table 1. In the initial runs, we assumed that on-axis echo strength was -47 dB $\pm$ 2.9 SD. This value was calculated from length frequency data on fish in the summer run using the dorsal-aspect equation of Love (1977). In subsequent runs we used the echo-strength statistics in Table 1, assuming that fish were oriented horizontally and ensonified 21° off dorsal aspect by Transducer 1 and 55 and 40° off ventral aspect by Transducers 2 and 4, respectively. Model output consisted of effective beam angle as a function of range from the transducers.

We compared estimates of fish passage and FGE from hydroacoustic and netting methods by examining scatter plots and correlation statistics. We compared catches of juvenile salmon in 1-3 h (mean = 2 h) net samples with hydroacoustic estimates for the same period (i.e., concurrent sampling). For FGE, we compared netting estimates with hydroacoustic estimates from concurrent sampling and from hydroacoustic sample periods that started when netting began (2000 h) and ended 4, 5, 6, 7, 8, or 9 h later. We expected some increase in precision of hydroacoustic estimates with increased sample duration. Every period of hydroacoustic sampling began with and included the start of the turbine and net sampling and included turbine shutdown when netting ended. We also plotted trends in daily estimates from both methods for the spring and summer, and examined confidence intervals of estimates to make recommendations for improving hydroacoustic sampling.

Results

We found significant correlations between the hydroacoustic counts of guided fish and catches of juvenile salmon in the gatewell (Figure 2). A base 10-log transformation removed a strong dependence of variances on means for both netting and hydroacoustic estimates. Normalization of data by transformation improved the coefficient of determination describing the fit of the points in the scatter plot by 10 %. For guided fish, mean gatewell catches were 11 times higher than concurrent hydroacoustic estimates when fish passage was low and two times higher when fish passage was high.

We also found significant correlations between fyke-net and hydroacoustic estimates of unguided fish, and the best fit was curvilinear (Figure 3). For unguided fish, which usually passed in lower numbers than guided fish, mean fyke-net catches were 10-13 times higher than hydroacoustic estimates. There were nine cases of zero counts of fish by hydroacoustics while 25-100 fish were netted.

We found significant correlations between hydroacoustic and net estimates of FGE when sampling was concurrent, when hydroacoustic sampling was extended to 4 h (2000-0000 h), and when hydroacoustic sampling was extended to 9 h (2000 to 0500 h; Figure 4). Data used to create scatter plots of concurrent estimates of guided fish passage (Figure 2), unguided passage (Figure 3), and FGE by hydroacoustics and netting are presented in Appendix 1. The best correlation was obtained when netting estimates of FGE were paired with 4-h hydroacoustic estimates (Figure 4). The 4-h hydroacoustic estimates explained 85 % of the variation in net estimates and 19 % more variation than hydroacoustic FGE based upon sampling concurrent with netting. The r^2 of the correlation between netting estimates of FGE and 9-h hydroacoustic estimates was 0.80, only 5% less than that for 4-h hydroacoustic samples paired with net samples (Figure 4). Correlation lines based upon netting estimates paired with estimates from 5-, 6-, 7-, 8-, and 9-h hydroacoustics samples did not differ significantly from correlations derived for netting data paired with data from 4-h periods of hydroacoustic sampling. With intercepts set to zero, ranges in slope and r^2 of these correlations were 0.86-0.91 and 0.79-0.85, respectively.

Confidence intervals on hydroacoustic estimates of FGE usually decreased as the duration of hydroacoustic sampling increased from concurrent with netting up to 4 h (Figure 5). The slope of the line indicates that average confidence limits for 4-h samples were about one half of those calculated for samples that were concurrent with netting. The SE in hydroacoustic estimates of fish passage increased as the mean rate of passage increased, which is typical for non-normal data, but the SE in FGE decreased as mean fish passage increased (Figure 6).

Original detectability modeling indicated that the effective beam angle of transducers sampling guided and unguided fish was asymptotic at about 9° for ranges > 8 m from transducers (BioSonics Incorporated 1997). Flow predictions for an ESBS (Nestler and Davidson 1995) suggested that water below the screen tip could be moving 1.1 m s^{-1} faster than water passing above the tip of the screen. Remodeling detectability with a flow velocity of 2.1 m s^{-1} for the down-looking transducer assuming a mean echo strength of -47 dB $\pm$ 2.8 SD indicated that the effective beam angle was only 8° at 8 m. However, it still approached an asymptote at about 9° at 13 m, the minimum range for fish detection in this beam. Remodeling of detectability using aspect-dependent estimates of on-axis echo strength (Table 1) produced effective beam angles of about 8.8° at 13 m for Beam 1 and about 7° for the up-looking transducer beams. Differences in these effective beam angles from those calculated by BioSonics Incorporated (1977) would have increased expanded hydroacoustic counts by only 2% for unguided fish and 27% for guided fish.

Fyke-net data of Brege et al. (1997) revealed a uniform lateral distribution across the width of the intake for yearling chinook salmon in spring and of sub-yearling chinook salmon in summer. These two species dominated numbers of fish passing in the respective seasons. In spring, similar numbers of yearling chinook were captured in columns of fyke nets on the left (290), middle (280), and right (297) side of the intake. Similarly, numbers of sub-yearling chinook were captured in nearly equal proportions in the left (798), middle (803), and right (761) column of fyke nets in summer. Analysis of variance, using net levels that captured at least 1 fish and days as replicate samples, indicated no significant difference in means in spring ($P = 0.913$; $N = 336$) or summer ($P = 0.922$; $N = 383$).

We found strong diel patterns in hydroacoustic estimates of total fish passage, with significantly higher numbers passing at night than during the day. The highest rates were from 2000-0000 h in spring and 2100-0000 h in summer (Figure 7). Diel patterns were much less obvious for FGE than for estimates of fish passage per hour (compare Figure 7 with Figure 8). Mean hydroacoustic estimates of FGE did not differ significantly between night and day periods in spring but were significantly higher during the day (81 %) than at night (62 %) in summer ($P = 0.0001$). The 95 % confidence intervals on the FGE estimates also were narrower at night than during the day.

Both netting and hydroacoustic methods detected a significant decline in the FGE of juvenile salmon from spring through summer (Figure 9). Hydroacoustic estimates averaged 92

± 2.5 % (95 % confidence interval) in spring and were about 10 % higher than netting estimates in late May and early June. Estimates of FGE by both methods exceeded 80 % from 8 May through 3 June but were < 60 % after 1 July. Hydroacoustic estimates of FGE averaged 67 ± 7.7 % (95 % confidence interval) in summer.

Discussion

Netting and hydroacoustics both provide imperfect estimates of FGE because of gear and sampling limitations, and unexplained variability and bias adversely affects the fit of correlations to these data. Nevertheless, comparison of sampling methods provides the opportunity to identify potential biases and highlights strengths and weaknesses of both methods. Bias cannot be measured with a single method and therefore is more insidious and difficult to quantify than sampling precision.

Both netting methods that we considered as a ground truth for hydroacoustics are less than 100% efficient, particularly for juvenile salmon. However, net efficiency was not and usually is not measured and used to correct for netting bias. Unless known numbers of fish were marked, introduced, and netted, the two types of nets were not calibrated and could have had different efficiencies. The assumption of equal net efficiencies may be incorrect and result in biased FGE estimates because the gatewell and turbine intake environments are dramatically different, as are the methods used to sample the two areas. Gessel et al. (1991) reported > 95% efficiency for gatewell dip-netting at Bonneville Dam. However, Steig and Ransom (1993) reported that many juvenile salmon guided by a bar screen at Rocky Reach Dam on the Columbia River were not sampled by a dip basket. They estimated that net-based FGE estimates would have more than doubled if net efficiency had been 100%. Other uncertainties arise from fish remaining in the gatewell slot before the test, lost through orifices during the test, or lost out the bottom of the gatewell downstream of the inlet flow vane, particularly at the end of a test. Fish also may accumulate in an intake while the turbine is off and fish are being removed from the gatewell before sampling.

We could not explain differences in hydroacoustic and net estimates of fish passage by lateral distributions of fish passing through the intake or by hydroacoustic detectability. Fyke-net data showed that the lateral distribution of fish passage across the intake was uniform. Therefore, the primary assumption for expanding hydroacoustic counts to the width of the intake was correct. Preliminary detectability modeling for -47 dB ± 2.8 SD fish indicated that effective beam angles used to calculate hydroacoustic expansion factors were reasonable. Even increasing expansion factors by 2-27% to account for effects of ensonification angle on detectability was inadequate to account for underestimates. A 75-mm fish ensonified 21° off dorsal aspect or 40-55° off ventral aspect should have been detectable with a -56-dB threshold within ± 3° of the main axis of the beam. The orientation of fish moving through intakes in unknown, but a 12-dB decrease in echo strength from the same fish can be expected with a change in ensonification angle from dorsal to head aspect (Love 1977). However, 90% of the fish could not have passed head (or tail) toward both the up-looking and down-looking transducers, which were aimed across each other (Figure 1).

Nevertheless, many fish must have passed undetected through the hydroacoustic beams or the effective beam angle was much less than predicted by detectability models, or both. Clearly, more research is needed to further develop and verify detectability models and their assumptions. The most uncertain assumption deals with how fish move through turbines and likely ensonification angles. However, flow velocities predicted from models (e.g. Nestler and Davidson 1995) also should be questioned because detectability is highly sensitive to the velocity of fish passing through the hydroacoustic sampling volume.

Two explanations are offered for the consistent underestimate of unguided fish passage by hydroacoustics. First, the down-looking transducer was aimed too far upstream and likely failed to detect many fish within 1 m downstream or upstream of the screen tip where flow is downward and rapid. Flow near the lower half of the 12.2-m long ESBS approaches at a right angle to screen's surface at about 1 m s^{-1}. Within about 1 m of the screen tip, flow is through or down the screen and accelerates to about 2.1-m s^{-1} near the tip. Stunned or disoriented fish on the screen within 1 m of the tip have been filmed moving down toward the bottom of the screen (Nestler and Davidson 1995). Mounting a transducer behind and below the pivot point of the screen and aiming it downward behind the screen would greatly increase the detection of unguided fish (e.g., Johnson et al. 1998 at Lower Granite Dam). This deployment would sample fish passing below the screen exclusively and would not miss fish passing near the screen tip. Second, fish passing > 1 m above the tip of the screen can still end up as unguided if they pass around the sides of the screen or down behind the inlet flow vane in the gatewell slot. Before the development of an inlet flow vane (Figure 1), Nestler and Davidson (1995) observed losses of 12 to 37 % of guided fish to the gap between the top of the ESBS and the vertical barrier screen. The inlet flow vane presumably reduces this loss, but its effectiveness has not been evaluated.

Hydroacoustic sampling only provided a relative index to fish passage. However, significant correlations between hydroacoustic and netting estimates indicate that the hydroacoustic data could be scaled by correlation coefficients to increase the accuracy of passage estimates. Ideally, nets would be calibrated to account for net efficiency bias. The significance of calibrating hydroacoustics to netting is that the nondestructive nature of hydroacoustic sampling permits it to be used much more extensively than netting. Once calibrated by netting, hydroacoustic sampling with consistent deployments could provide quantitative estimates for many turbines.

Our results and other reported correlations of hydroacoustic counts and net catches suggest that that no universally applicable correlation exits between the sampling performance of nets and hydroacoustic deployments. This is not surprising given the large number of possibilities for transducer deployments and the physical differences between intakes and physical capture methods. For example, Ransom et al. (1996) reported ratios of net catches to hydroacoustic counts of 3.4 for a sluiceway at Ice Harbor Dam ($r^2 = 0.92$; N = 26) and 1.3 for a turbine intake at Wanapum Dam ($r^2 =0.92$; N =10). Magne et al. (1988) found slopes 0.95 for net estimates regressed on hydroacoustic estimates for Intake 13a ($r^2 = 0.61$; N = 26) and 3.41 for Intake 17b ($r^2 = 0.94$; N = 13) at the second powerhouse at Bonneville Dam. Slopes of three regression lines reported for smolt passage at Turbine 3 at the first powerhouse of Bonneville Dam were 0.99, 1.0, and 1.33 (Thorne and Kuehl 1989).

Correlations of hydroacoustic and netting estimates of FGE were better than those for guided and unguided components of FGE because of compensating errors in the numerator and denominator of ratio estimator. The assumption of equal detectability of guided and unguided smolts must have been reasonable most of the time given strong correlations between hydroacoustic and netting estimates of FGE with correlation slopes approaching 1. However, hydroacoustic sampling may have overestimated FGE when netting estimates of fish passage were high. Hydroacoustic estimates of unguided fish passage remained nearly constant at 7.7-10.0% of netting estimates while those for guided passage increased from 11% of netting estimates when passage was low to 25-50% of net estimates when passage was high.

Extending hydroacoustic sampling from 2000 to 0000 h increased the precision of FGE estimates and provided the best correlation with net estimates ($r^2 = 0.85$; N = 39). The slope of the correlation line with the intercept forced through zero was 0.91, indicating less bias than observed for correlations for guided and unguided fish passage. Four-hour hydroacoustic sampling explained 19 % more variation than concurrent sampling because hydroacoustic estimates increased in precision as sampling duration increased. Confidence intervals for extended sampling from 2000 to 0000 h were about one half of those for concurrent sampling (Figure 5), and the SE of hourly FGE was inversely correlated with the mean hourly rate of passage (Figure 6). Unless variation in hydroacoustic FGE increases because of diel changes, increased precision with increased sampling is inherent in the variance formula.

Sampling time can be increased either by sampling more minutes per hour or by increasing sampling hours, provided diel changes do not increase variability. The greatest improvement in the fit and slope of the correlation was obtained by extending hydroacoustic-sampling duration to 4 h. Correlations based upon 5-9 h hydroacoustic samples were similar, producing r^2 statistics within 3-5% of the correlation for 4-h hydroacoustic sampling and 14-16 % higher than the r^2 for concurrent sampling. Although passage rates declined significantly after midnight (Figure 7), mean FGE drifted only slightly from what was estimated for the 2000-0000 h period (Figure 8). In summer, mean hydroacoustic estimates of FGE were significantly higher during the day (mean = 78%) than at night (mean = 60 %), but no differences were apparent in spring.

Strong correlations between estimates of FGE derived from netting and hydroacoustic sampling are reassuring and useful because both methods have advantages that can be exploited to improve overall sampling effectiveness at a project. Netting can provide estimates of fish passage and guidance efficiency by species but is labor intensive, injures or kills fish, and cannot be used for more than a few hours per day at 1 or 2 of 48 intakes. The restriction of physical capture to one or two intakes prevents biologists from evaluating spatial variation in fish passage and FGE among intakes. Hydroacoustic sampling can be applied to many or all intakes, 23 h per day, without adversely affecting fish. However, hydroacoustic sampling provides only a relative index to fish passage unless calibrated against unbiased netting and cannot provide species-specific estimates without physical capture and visual inspection to accurately estimate species composition. If the goal is to determine the efficiency of many screens during spring and summer runs, hydroacoustics can provide a meaningful index. However, some netting should be required to calibrate hydroacoustic estimates if fish passage is important or if species-specific estimates of FGE are desired.

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Table 1. Variables and values used for modeling hydroacoustic detectability for each of three hydroacoustic beams shown in Figure 1.

Input Variable	Beam 1	Beam 2	Beam 3
Nominal beam angle	6 °	6 °	6 °
Angle of flow across beam	25	15	0
Ping rate (pings / s)	10	10	10
Flow rate (m / s)	1.2	1.2	2.1
Ensonified aspect for a horizontal fish	21 ° off dorsal	55 ° off ventral	40 ° off ventral
Mean on axis echo strength	-49	-53	-51
Standard deviation in on axis echo strength	1	1	1
Minimum target strength (on axis)	-56	-56	-56
Minimum number of echoes	4	4	4
Maximum ping gap between echoes	4	4	4
Fish speed in random direction (m / s)	0.03	0.03	0.03

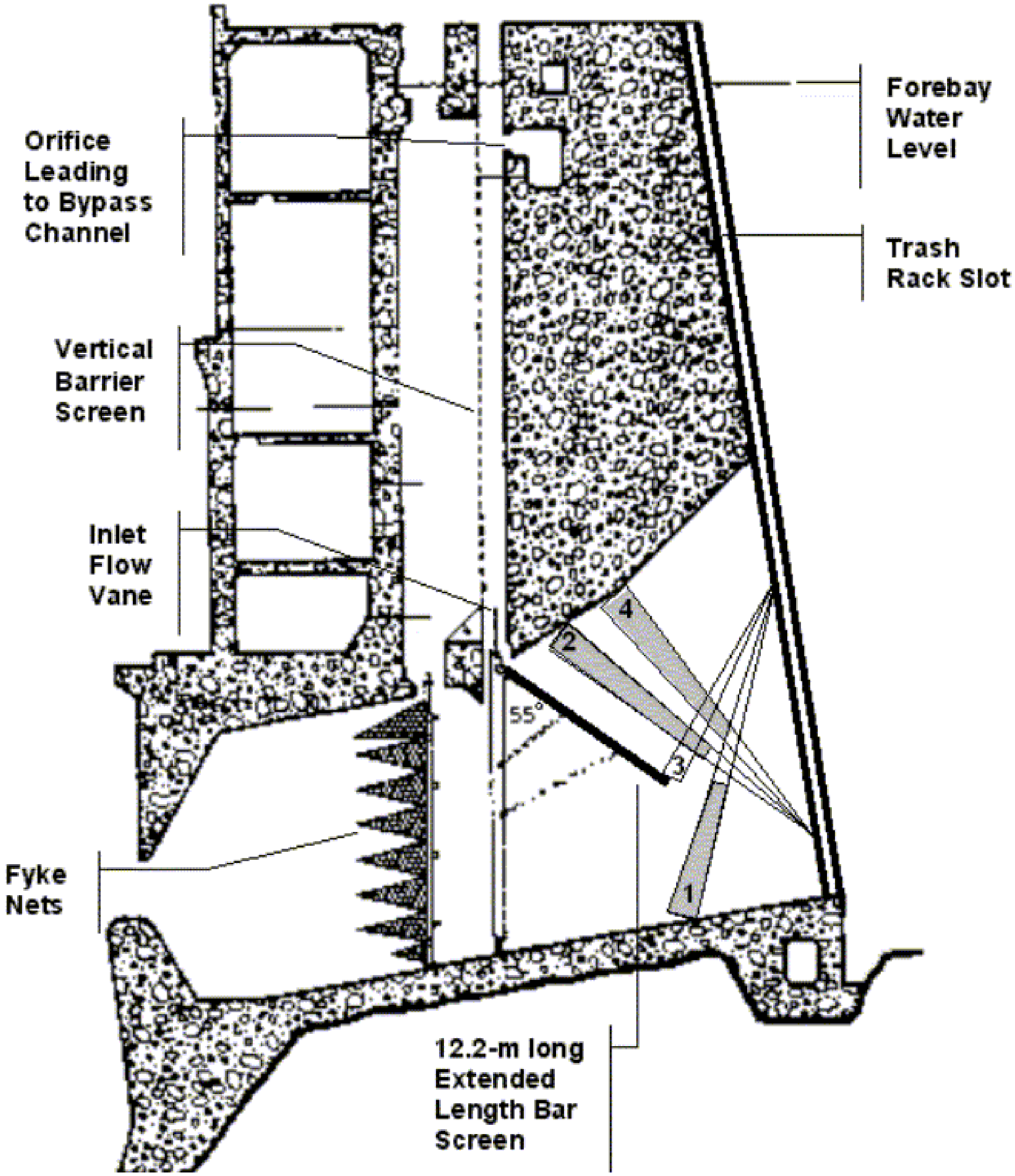
Appendix 1. Comparison of concurrent hydroacoustic and netting estimates of guided and unguided juvenile salmon passage and fish-guidance efficiency (FGE) at intake 7b at John Day Dam in spring and summer, 1996.

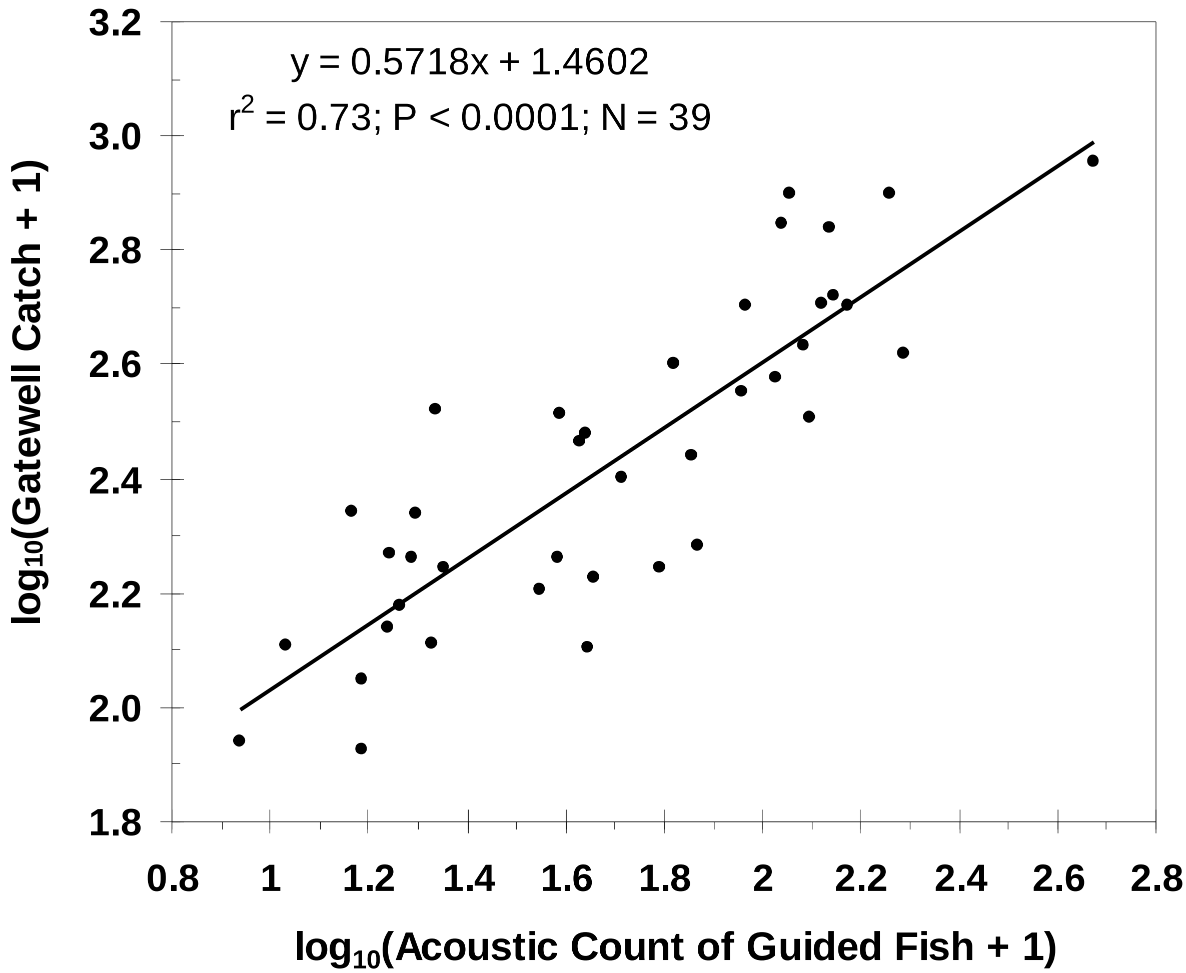
Gregorian Date	Acoustic Estimate of Guided Fish	Gatewell Dipping Estimate of Guided Fish	Acoustic Estimate of Unguided Fish	Fyke Net Estimate of Unguided Fish	Acoustic FGE	Netting FGE
5/08/96	105.6	377	7.9	60	93.0	86.3
5/09/96	38.0	326	0.0	62	100.0	84.0
5/10/96	41.5	291	0.0	62	100.0	82.4
5/11/96	112.8	794	10.0	101	91.9	88.7
5/12/96	147.6	502	0.0	78	100.0	86.6
5/15/96	138.5	523	0.0	83	100.0	86.3
5/16/96	72.8	191	0.0	29	100.0	86.8
5/17/96	89.6	355	10.1	50	90.0	87.7
5/18/96	91.5	502	2.1	63	97.9	88.8
5/19/96	180.4	790	0.0	99	100.0	88.9
5/20/96	472.6	903	5.0	98	99.0	90.2
5/21/96	135.8	690	2.8	80	97.8	89.6
5/22/96	109.0	699	3.0	103	97.3	87.2
5/23/96	65.2	400	2.8	56	95.6	87.7
5/24/96	192.4	416	4.3	50	98.0	89.3
5/25/96	131.2	507	5.8	74	95.6	87.3

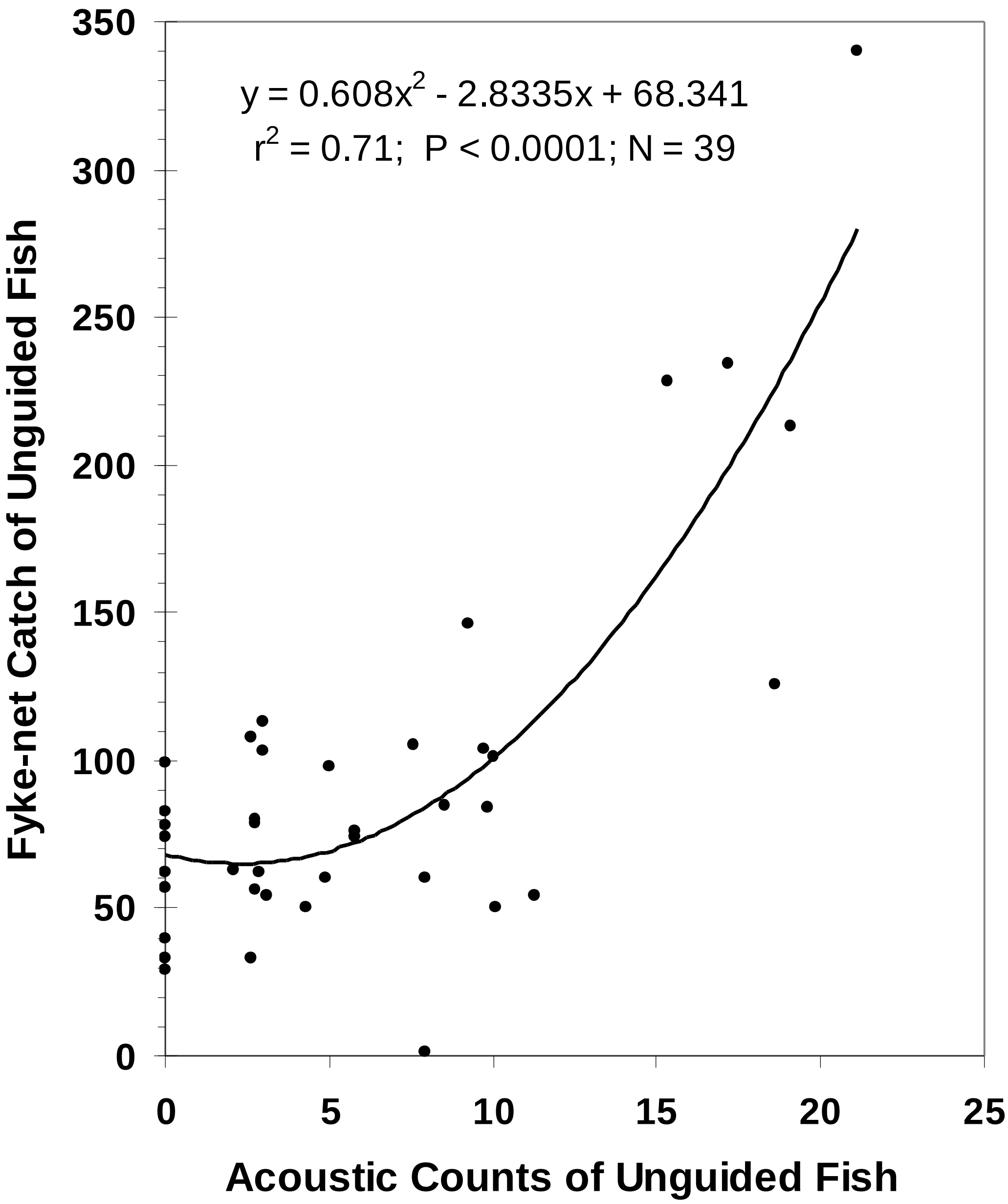
5/28/96	50.6	251	2.6	33	94.4	88.4
5/29/96	124.2	321	4.9	60	96.1	84.3
5/30/96	37.4	182	0.0	33	100.0	84.7
5/31/96	71.2	275	0.0	40	100.0	87.3
6/24/96	44.4	167	3.1	54	93.6	75.6
6/25/96	21.6	174	2.8	79	88.0	68.8
6/26/96	42.6	301	2.9	62	93.5	82.9
6/27/96	43.4	126	7.6	105	84.3	54.5
6/28/96	60.7	174	9.8	84	85.9	67.4
6/29/96	120.8	429	3.0	113	97.6	79.2
6/30/96	7.7	86	0.0	57	100.0	60.1
7/02/96	14.4	111	0.0	74	100.0	60.0
7/03/96	13.7	219	19.1	213	42.4	50.7
7/08/96	16.6	185	15.4	228	53.1	44.8
7/09/96	17.4	150	17.2	234	50.0	39.1
7/10/96	34.4	160	11.3	54	75.6	74.8
7/11/96	18.5	182	9.7	104	65.5	63.6
7/12/96	18.7	217	5.8	76	76.0	74.1
7/15/96	14.3	83	9.2	146	60.9	36.2
7/16/96	16.4	137	2.6	108	84.2	55.9
7/17/96	20.6	332	21.1	340	50.0	49.4
7/18/96	9.8	127	18.6	126	34.5	50.2
7/19/96	20.3	128	8.5	85	69.0	60.1

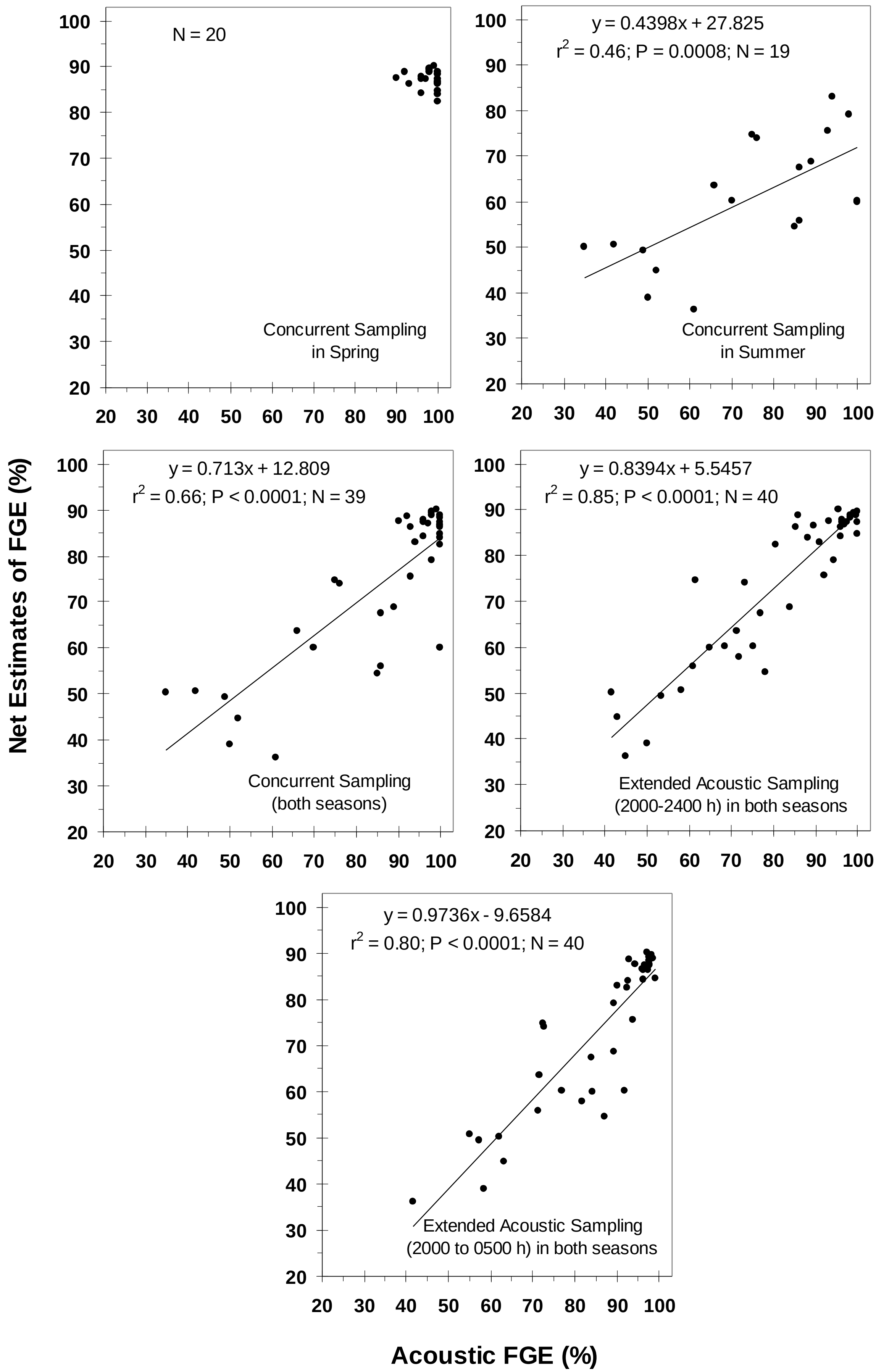
List of Figures

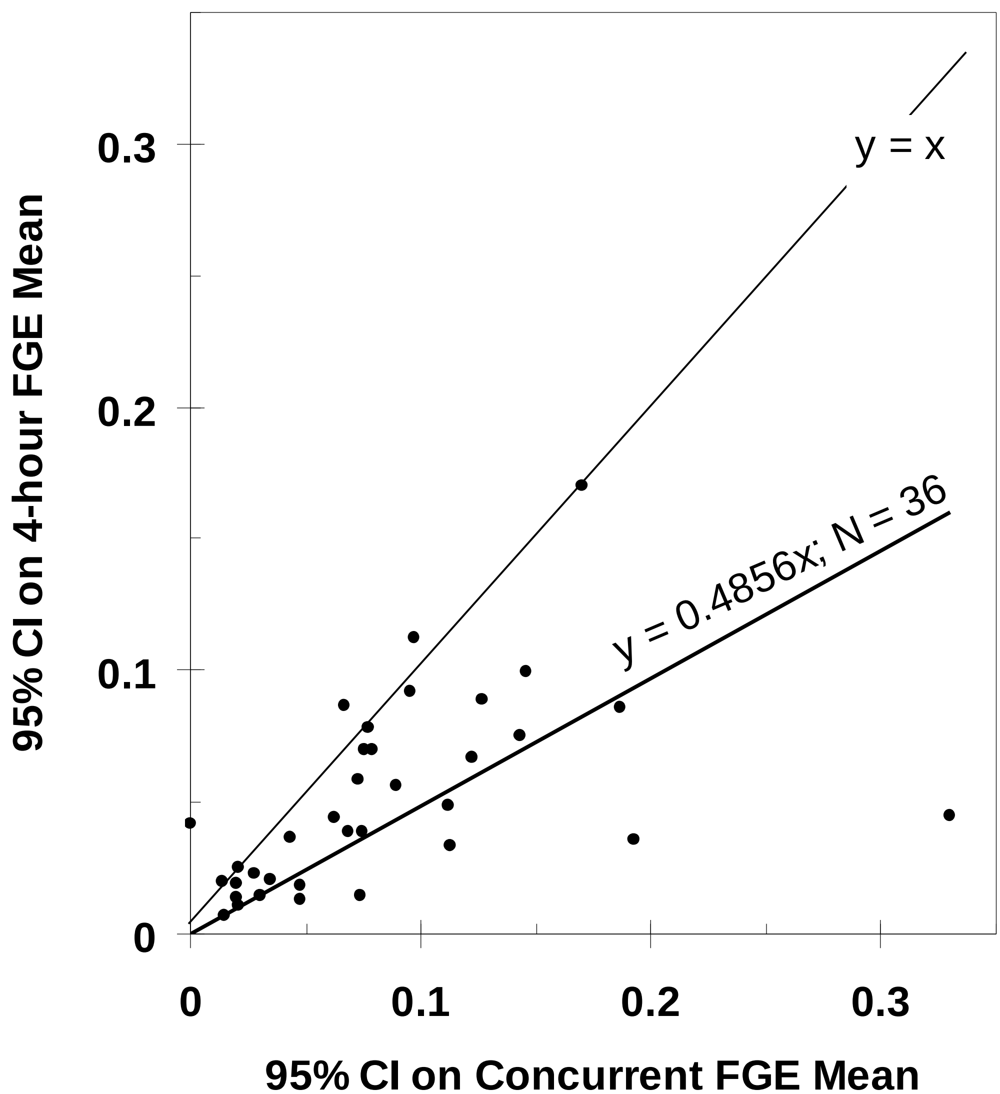
collected in 4-h samples (2000-0000 h) and netting data in samples lasting 1 to 3 h per day (from 2000 to 2100, 2200, or 2300 h).

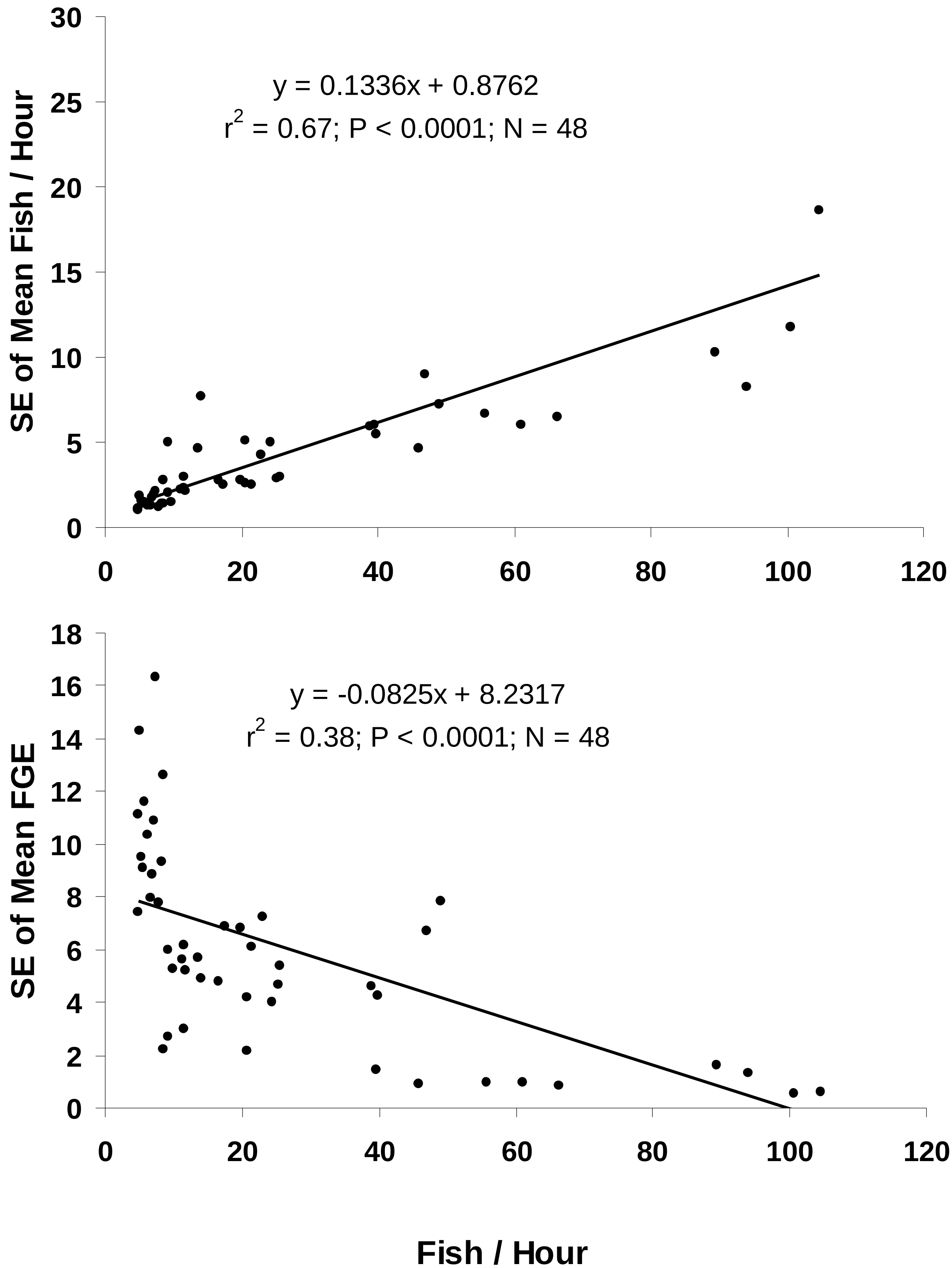



y = 0.5718x + 1.4602
r^2 = 0.73; P < 0.0001; N = 39
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
$\log_{10}$(Gatewell Catch + 1)
$\log_{10}$(Acoustic Count of Guided Fish + 1)

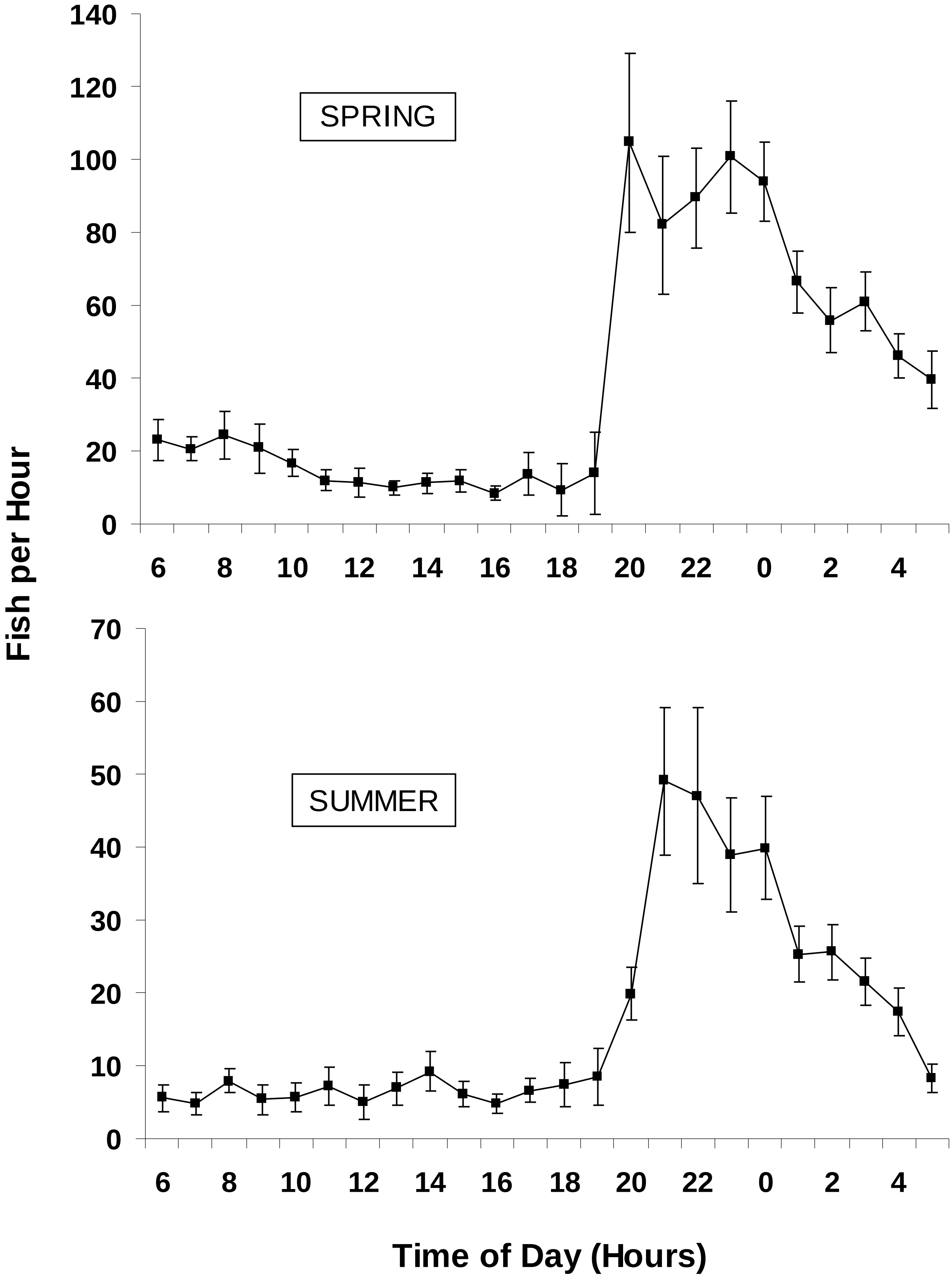

y = 0.608x2 - 2.8335x + 68.341
r2 = 0.71; P < 0.0001; N = 39
Fyke-net Catch of Unguided Fish
Acoustic Counts of Unguided Fish
0
50
100
150
200
250
300
350
0
5
10
15
20
25

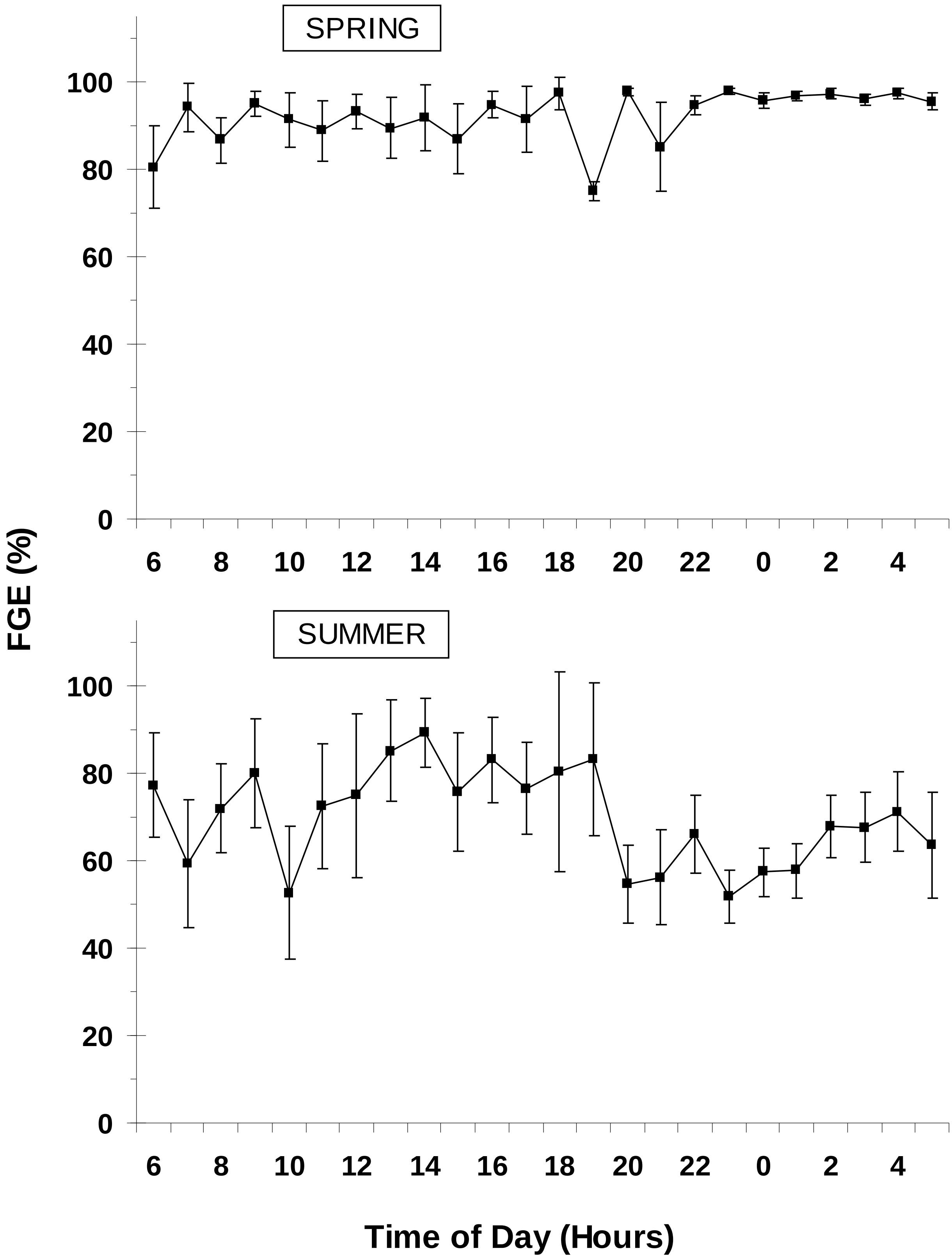

N = 20
Concurrent Sampling
in Spring
y = 0.4398x + 27.825
r2 = 0.46; P = 0.0008; N = 19
Concurrent Sampling
in Summer
y = 0.713x + 12.809
r2 = 0.66; P < 0.0001; N = 39
Concurrent Sampling
(both seasons)
y = 0.8394x + 5.5457
r2 = 0.85; P < 0.0001; N = 40
Extended Acoustic Sampling
(2000-2400 h) in both seasons
y = 0.9736x - 9.6584
r2 = 0.80; P < 0.0001; N = 40
Extended Acoustic Sampling
(2000 to 0500 h) in both seasons
Net Estimates of FGE (%)
Acoustic FGE (%)

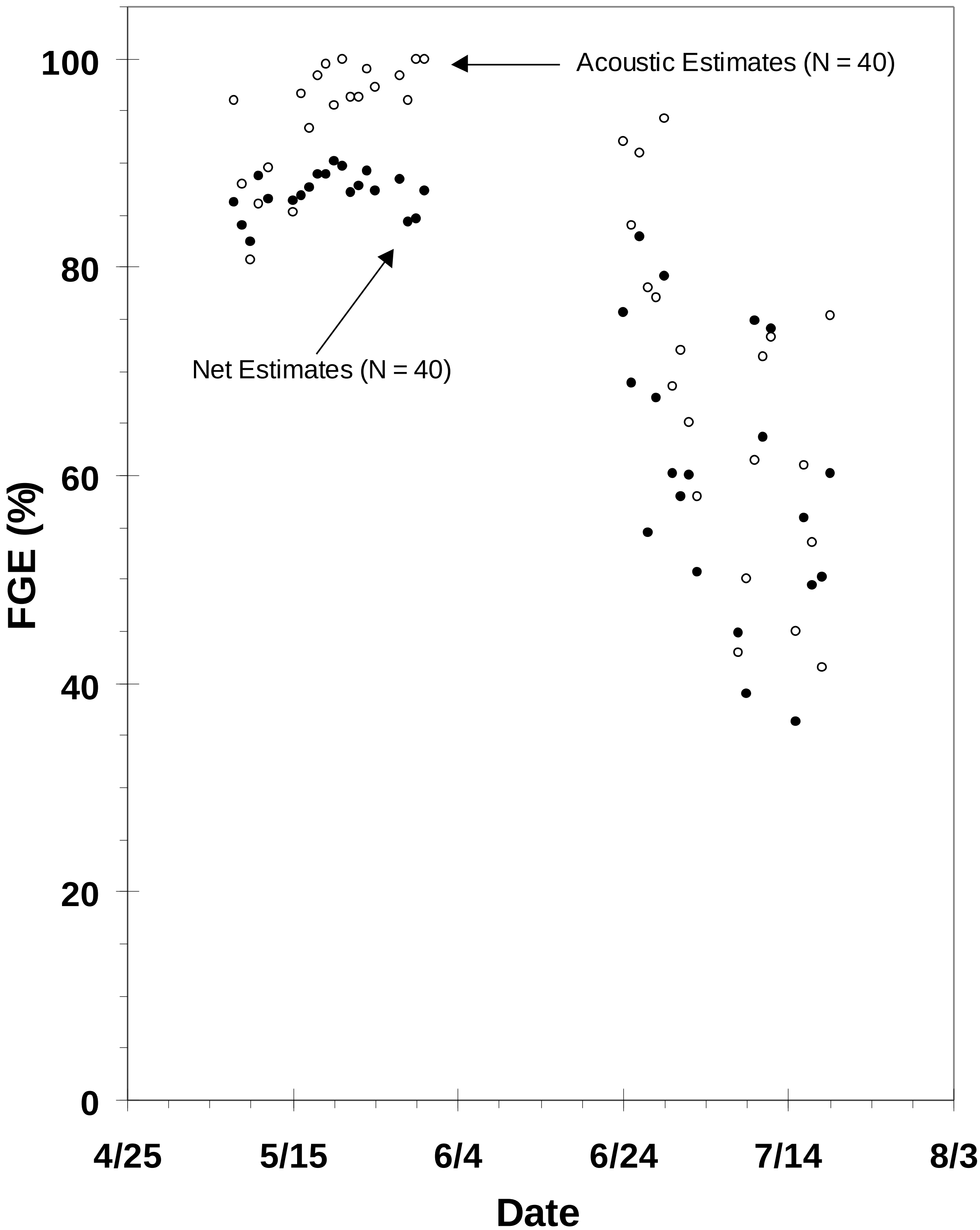

y = x
y = 0.4856x; N = 36
0.3
0.2
0.1
0
95% CI on 4-hour FGE Mean
0
0.1
0.2
0.3
95% CI on Concurrent FGE Mean



y = 0.1336x + 0.8762
r2 = 0.67; P < 0.0001; N = 48
SE of Mean Fish / Hour
0
5
10
15
20
25
30
0
20
40
60
80
100
120
y = -0.0825x + 8.2317
r2 = 0.38; P < 0.0001; N = 48
SE of Mean FGE
0
2
4
6
8
10
12
14
16
18
0
20
40
60
80
100
120
Fish / Hour


SPRING
SUMMER
Fish per Hour
Time of Day (Hours)
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70
6
8
10
12
14
16
18
20
22
0
2
4


SPRING
SUMMER
FGE (%)
100
80
60
40
20
0
6
8
10
12
14
16
18
20
22
0
2
4
Time of Day (Hours)



Acoustic Estimates (N = 40)
Net Estimates (N = 40)
FGE (%)
100
80
60
40
20
0
4/25
5/15
6/4
6/24
7/14
8/3
Date